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RADIO EMISSION OF VENUS AT 4 MILLIMETERS

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RADIO EMISSION OF VENUS AT 4 MILLIMETERS.

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ABSTRACT.

The method applied for the observation of Venus' radio emission in the 4 mm. wavelength is here described. The observations were made with the aid of a 22-meter radiotelescope of the the Physical Institute of the USSR Academy of Sciences during March- May 1961. The brightness temperature referred to the visible part of the disk of the planet, was found to be minimum in the lower conjunction and equal to $390^\circ \pm 120^\circ$ K. The brightness temperature increases somewhat with the increase of distance from the lower conjunction. Since the antenna parameters were not determined with sufficient accuracy, it was only possible to estimate this increase, which by the end of observations did not exceed 230° K. At that time, the relative area of the illuminated part of the disk was 0.34.

The obtained value of brightness temperature at 4 mm, results very close to that observed in the 8 mm wavelength, and this seems to suggest a comparatively low radiation absorption in planet's atmosphere.

Obviously, further comparisons with the results obtained in the centimeter band will allow conclusions concerning the general physical conditions on Venus.

Author

I. INTRODUCTION

Measurements of Venus' self-radio emission offer a great interest, for they allow the obtention of a series of important informations on planet's temperature regime, on the character of its surface and atmosphere composition, and also on certain of the rotation elements. To clarify the mechanism of Venus' radio emission and the part its atmosphere plays in the absorption of the surface-emitted radiation, a particular interest is offered by the observations in shortest possible wavelengths of the centimeter and millimeter bands. However, progressing toward shorter waves is beset with considerable dif iculties connected with the rise of absorption in the Earth's atmosphere, and the deterioration of the parameters of the receiving devices. So far, observations of Venus' radio emission were conducted in wavelengths not shorter than 0.8 cm [1, 2].

During the period March—May 1961, observations of Venus' radio emission were carried out at 4 mm by means of a 22-meter radiotelescope of the Institute of Physics in the name of P. N. Lebedev of the USSR Academy of Sciences, [3]. (The utilized 4 mm radiometer was worked out at NIRFI of the Gor'kiy State University in the name of N. I. Lobachevskiy). A brief preliminary paper concerning these observations was published in [4]. Described is in the current paper the method of observation and the processing of the results obtained which at the same time are brought out in detail.

II. METHOD OF OBSERVATIONS

The method applied for the measurement of Venus' radio emission is analogus to that described earlier [2].

Along one coordinate — the height, the planet was followed by the antenna of the radiotelescope. In the presence of optical visibility, which prevailed during most of observations, the tracking was effected in the regime of visual guiding with the aid of a optical visor from the upper cabin of the radio telescope. During the isolate. days near the lower conjunction, and because of absence of visibility resulting in undesirable gaps in observation, the tracking in height was realized by automation with a complementary correction [5].

Because of the daily rotation of the Earth, the antenna was alternately assigned a velocity somewhat higher and lower than the azimuthal velocity of Venus' own rotation. Multiple passings of the planet were thus obtained from left to right and vice-versa. In order to obtain the angular scale in passing's readings, additional markings were placed besides the usual minute time markings from the chronometer, that corresponded to a known angular distance in the pictorial plane.

To avoid errors connected with the inaccurate knowledge of the mutual disposition of the optical axis of the visor and of antenna's electrical axis, a few series of Venus' passage for a different visor position in height were recorded. At time of processing the series of readings corresponding to the maximum signal was sorted.

Periodical calibrations of the intensity of the received signal were conducted in the course of observations by means of registering the emission of an absorbing wedge introduced into the signal's path by remote control. In clear days, an additional calibration was also conducted at the end of observations by atmosphere radio emission at various zenithal distances of the antenna axis. In order to compute the Venus' brightness temperature, radio emission from the Moon was also measured in the course of the observation period.

3. METHOD OF THE PROCESSING OF RESULTS

The directly measured quantity during radioastronomical observations is the antenna temperature T_A of the investigated source of emission. The antenna temperature of Venus is

$$T_{A_{\venus}} = \frac{\int\limits_{(4\pi)} T(\Omega)\, F(\Omega)\, d\Omega}{\int\limits_{(4\pi)} F(\Omega)\, d\Omega} \qquad (1)$$

where T (Ω) is a function describing the brightness temperature distribution along the Venus' disk, F (Ω) is a function describing the antenna's radiation pattern.

Introducing as usual the planet's brightness temperature, averaged over the disk

$$T_{\venus} = \frac{\int\limits_{\Omega_{\venus}} T(\Omega) F(\Omega)\, d\Omega}{\int\limits_{\Omega_{\venus}} F(\Omega)\, d\Omega}, \qquad (2)$$

where $\Omega_{\venus}$ is the solid angle of the visible disk of Venus, and, taking into account that beyong that angle T (Ω) = 0, we obtain

$$T_{A_{\venus}} = T_{\venus} \frac{\int\limits_{\Omega_{\venus}} F(\Omega)\, d\Omega}{\int\limits_{(4\pi)} F(\Omega)\, d\Omega} = T_{\venus}(1 - \beta_{\venus}). \qquad (3)$$

Here $\beta_{\venus}$ is the antenna's dispersion factor outside the visible disk of Venus.

In order to determine the Venus' brightness temperature directly from (3), one must know the antenna's total radiation pattern. But this is beset with considerable difficulties and is effected with great errors. The simplest and most accurate means of temperature measurement of an emitting object is the comparison with any well known cosmic source of radio emission. That is why in the current work the brightness temperature of Venus was determined by comparison with the brightness temperature of the central part of the Moon's disk, considered well known [6].

Inasmuch as the measurements of Venus' and Moon's radio emission were, generally speaking, conducted at differe t times, and under mutually different meteorological conditions, we utilized, as was already mentioned, an intermediate calibration either by the emission of an absorbing wedge [7] , or according to the variation of atmosphere's natural emission at different zenithal distances [6].

It may be shown, that the antenna temperature of Venus is

$$T_{A♀} = q_♀ T_0 \left[1 + \Delta + \beta \frac{T_н - \overline{T}_н}{\gamma_♀ T_0} + \frac{T_к - T_0}{\gamma_♀ \eta T_0} \right]. \quad (4)$$

Here the following designations were introduced :

$$q_♀ = \frac{d_♀ - d_н}{d_к - d_н},$$

where $d_♀$, $d_н$ and $d_к$ are respectively the deflections of the radiometer's output device at antenna guiding at Venus, its immediately neighboring sky region, and also at asbrrbing wedge introduction in the signal's path. Further, T_0 is the temperature of the near-Earth's atmosphere layer at time of observation ; Δ is the correction, accounting for the atmosphere anisothermicity [6]; $T_н$ is the effective emission temperature of the parcel of the sky near Venus ; $\overline{T}_н$ is the temperature of the surrounding background, averaged over the lateral and rear lobes of the antenna ; $\gamma_♀$ is the absorption coefficient in the Earth's atmosphere in the direction toward Venus ; T_k is the temperature at which the absoring wedge finds itself ; η is the efficiency of the radiotelescope's antenna ; β is the antenna's dispersion factor outside the solid angle (near the direction toward Venus), in which the sky's radiobrightness may be estimated constant.

We may write correlations, similar to (3) and (4), for the antenna temperature of the center of the Moon's disk

$$T_{A_л} = q_л T_0' \left[1 + \Delta' + \beta \frac{T_н' - \overline{T}_н'}{\gamma_л T_0'} + \frac{T_к' - T_0'}{\gamma_л \eta T_0'} \right]. \quad (5)$$

All the designations in (5) have a sense analogus to that admitted in (4). Besides it is obvious that

$$T_{A_л} = T_л (1 - \beta_л), \quad (6)$$

where $T_л$ - is the brightness temperature of the central part of the Moon's disk, determined similarly to (3) ; $\beta_л$ is antenna's dispersion factor outside the visible disk of the Moon. (see infrapaginal note ext page *).

When measurements of Moon's and Venus' radio emission are conducted under comparable atmospheric conditions, and besides, the investigated sources are located during observations at about the same zenithal distances (and sufficiently small), the components in square brackets of (4) and (5), may be considered equal **.

Then, we may obtain from (3), (4), (5), and (6) :

$$T_{♀} = T_{л} \frac{q_{♀}}{q_{л}} \frac{1-\beta_{л}}{1-\beta_{♀}} \frac{T_0}{T_0'} \qquad (7)$$

Let us now pass to the second method of radiometer calibration — by the difference of the atmosphere's eigen radio emission for two different zenithal distances. Usually, the directions toward the horizon and at a 10° angle to the horizon were chosen for such points during observations. In the first case the antenna is directed toward the region with a temperature equal to that of the air in the near-terrestrial layer (since the absorption coefficient of the 4 mm waves in the Earth's atmosphere is sufficiently great [8]. The brightness temperature of the sky portion at 10° above the horizon ($T_{нк}$) may be computed by means of well known values of radiowave absorption coefficients in the 4 mm band in oxygen and water vapor, and also of the effective heights of O_2 and H_2O in the Earth's atmosphere [9]. The quantity of water vapors in the atmosphere on the day of measurement was determined by the data on air moisture supplied by a nearby meteorological station. Thus, at calibration by atmosphere, the Venus' brightness temperature is equal to

$$T_{♀} = q_{♀} \frac{1-\beta}{1-\beta_{♀}} \gamma_{♀} (T_0 - T_{нк}). \qquad (8)$$

An analogous correlation for the radiobrightness of the central part of the Moon has the form

$$T_{л} = q_{л} \frac{1-\beta}{1-\beta_{л}} \gamma_{л} (T_0' - T_{нк}'). \qquad (9)$$

---

*) and **) see Appendix.

From formulas (8) and (9) it is easy to obtain

$$T_♀ = T_л \frac{q_♀}{q_л} \frac{1-\beta_л}{1-\beta_♀} \frac{\gamma_♀}{\gamma_л} \frac{T_0 - T_{нк}}{T_0' - T_{нк}'}. \qquad (10)$$

In deriving correlations (8) and (9) it was assumed that the radiation of the background surrounding the antenna, averaged over the lateral and rear lobes of antennas, may be neglected on account of the smallness of antenna's rotation angle.

The error considered acceptable at such calibration method does not exceed $\pm$ 3% $\div$ 5%, provided the measurements of Venus' and Moon's emissions are conducted at sufficient height of these sources above the horizon (30°), which was satisfied in an overwhelming majority of cases. However, calibration by atmosphere is only applicable in time of steady cloudless weather, when the absorption in the atmosphere lends itself to estimation, Thus, the second calibration method was only used to check the first, fundamental method.

The ratio

$$\frac{1-\beta_л}{1-\beta_♀} = \frac{\int_{\Omega_л} F(\Omega)\,d\Omega}{\int_{\Omega_♀} F(\Omega)\,d\Omega}, \qquad (11)$$

enters in formula (7) as well as in formula (9). To determine it, the antenna radiation pattern must be known within the limits of dimensions of the lunar disk. This problem was solved as follows: The width of the principal lobe of the antenna radiation pattern at the 3 db level was determined by the averaged values of Venus passage through the radiation pattern of the radiotelescope. The results of averaging of several recordings of the passage of Venus, obtained on 2 April 1961 are presented in Fig. 1 (solid broken curve). The dotted line, which is the curve of Venus passage, computed in the assumption that the radiation pattern of the antenna represents a Gauss curve of 1.6 width at the 3 db. level. The computation was carried out by means of graphical integration. Subsequently, it was considered that the radiation pattern above the 3 db level coincides with the Gauss curve of 1.6 width.

Below that level the pattern model was chosen within the bounds of the lunar disk's angular dimensions in such a way, that the computed passing of the Sun through the radiation pattern coincide with that obtained through the experiment. The computation was also made by the graphical integration method. It was effected separately for the passages of the Sun along the azimuth and the height. For the calculation, chosen was a corresponding model of pattern, considered to be symmetrical rotation figure. It is well known that in that case, the two-dimensional integrals are reduced to one-dimensional in (11) :

$$\frac{1-\beta_{Л}'}{1-\beta_{♀}} = \frac{\int\limits_{\theta_{Л}} F(\theta)\sin\theta d\theta}{\int\limits_{\theta_{♀}} F(\theta)\sin\theta d\theta}, \qquad (12)$$

where $\theta_{Л}$ and $\theta_{♀}$ are the visible angular radii of the lunar and venusian disks respectively. The integrals entering into the expression (12) were computed graphically.

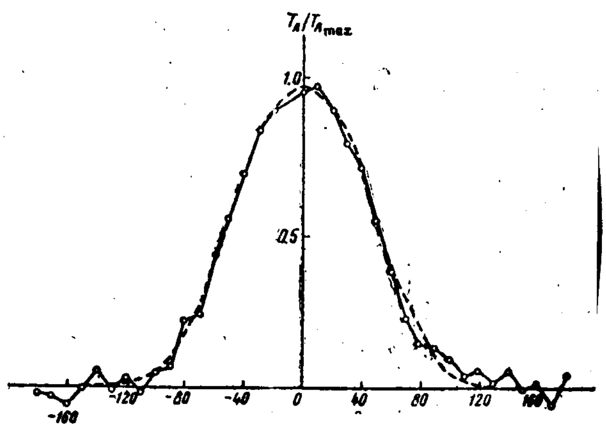


Fig. 1. Averaging of a few recordings of Venus' passing on 2 April 1961.

In connection with the fact that the experimental curves of Sun's passage resulted different at the beginning and the end of the observation period, computations were conducted for both passages, and the respective diagrams for 22 March and 28 May are plotted in Fig. 2. During the intermediate days the antenna parameters were determined by linear interpolation. The notable broadening in the radiation pattern of the antenna having taken place during the observations, was apparently the result of thermal distortions of the mirror due to air temperature increase during the period from March to May.

A similar deterioration of antenna parameters was also noticed at the observation of Venus' radio emission in the 8 mm wavelength, [10].

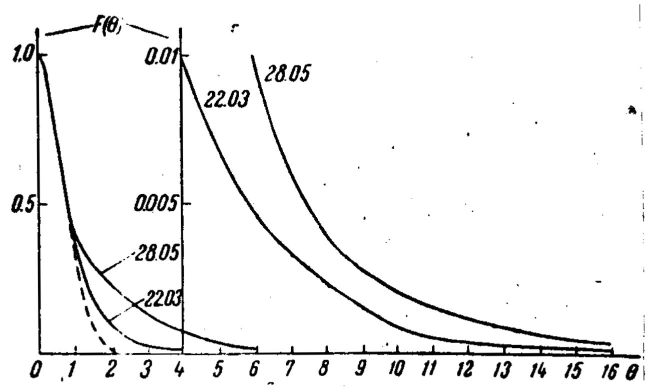
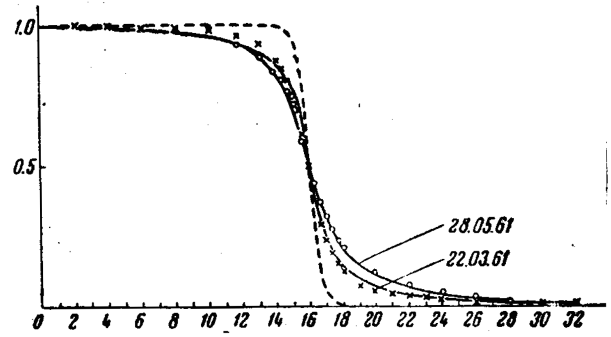


Fig. 2. Diagram of the radiation pattern of the radiotelescope antenna for 22 March and 28 May.



Distance between the center of the Sun and the axis of the diagram in angular minutes.

Fig. 3. Curves of the Sun's passage, computed by the diagrams of Fig. 2. Crosses and circles indicate the experimental points for 22 March and 28 May

Plotted are in Fig. 3 the curves of Sun's passage at the beginning and at the end of observations, computed according to Fig. 2 graphs.

The relative error in the measurement of the antenna parameter $(1-\beta_{\Omega})/(1-\beta_{♀})$ constitutes about $\pm 15\%$. However, its absolute value is known with less accuracy, inasmuch as an error of $\pm 5\%$, linked with the fact that certain simplifications are made when processing the readings of solar radio emission: Indeed, the Sun was assumed to be a uniformly bright disk with sharp boundaries. Thus, when determining the antenna parameter $(1-\beta_\pi)/(1-\beta_♀)|$, a ±20% error is possible.

Together with the calibration error of the radiometer, the total mean-square error in the measurement of intensity of Venus' radio emission constitutes ± 30%.

4. RESULTS OF OBSERVATIONS

The observations of Venus' radio emission were carried out from 19 March to 28 May 1961. Several dozens of recordings of Venus' passage through the radiotelescope's radiation pattern were made during every day of observation. The readings obtained were averaged, and the mean Venus' antenna temperature $T_{A_♀}$ and brightness temperature $T_♀$ (the former corrected for atmosphere absorption and the latter — averaged) were computed for every day. The results of processing of all experimental data are plotted in the graphs of Fig. 4 and 5, where $T_{A_♀}$ and $T_♀$ are shown as function of the date of observation.

Vertical cuts in the graphs indicate the mean-square errors in the determination of the average computed for every day of observations. The sharp rise and drop of the antenna temperature $T_{A_♀}$, visible in the graph of Fig. 4, are explained by the variation of distance between Venus and the Earth, taking place during the period of observations. The highest antenna temperature was near the lower conjunction (arrow of Fig. 4). The brightness temperature of Venus is minimum near the lower conjunction and equal to

$$T_{♀\,\text{нс}} = 390 \pm 120^\circ \text{K}.$$

As may be seen from Fig. 5, there is a tendency for $T_♀$ to rise when moving toward either side from the lower conjunction. This may be construed as the phase course of its radio emission, apparently linked with the increase of the visible part of Venus' disk illuminated by the Sun. This is better outlined in Fig. 6.

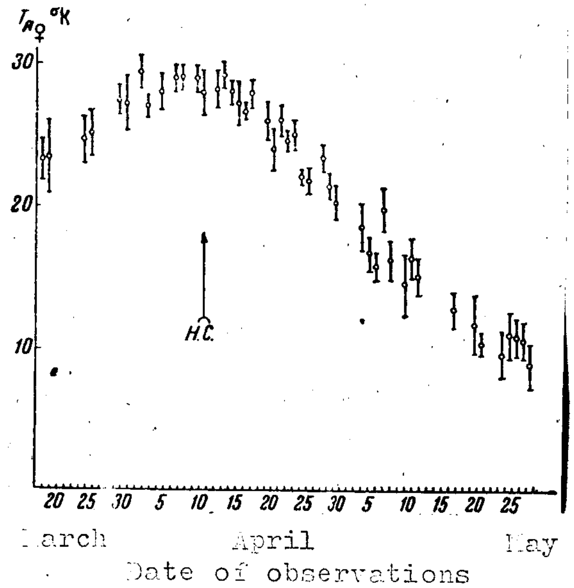


Fig. 4. Dependence of Venus' antenna temperature on the date of observation. The arrow indicates the date of the lower conjunction.

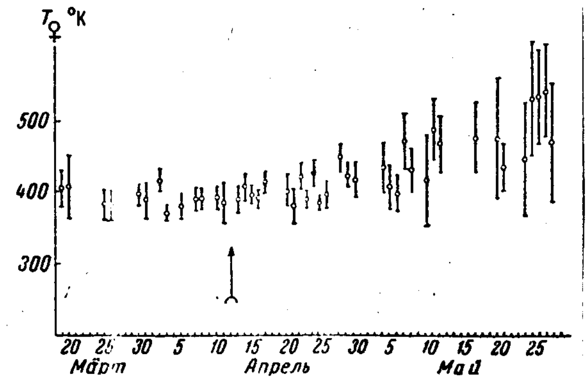
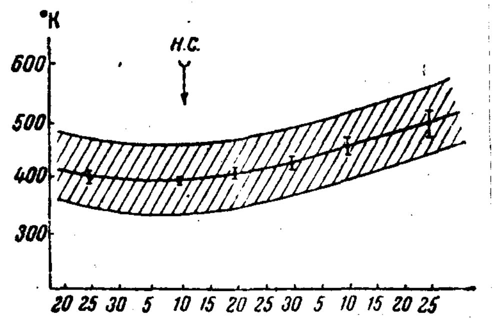


Fig. 5. Dependence of Venus' brightness temperature on the date of observation

It must be noted that the phase dependence curve may be only determined with precision of the band shaded in Fig. 6, which is linked with the inaccuracy of antenna parameters' determination at the beginning and at the end of observations. Besides, the whole curve of phase dependence may shift up and down by the quantity corresponding to the measurement error, say ±30%.

For the theory of Venus' radio emission a significant interest is offered by the difference in the magnitude of brightness temperature for its various phases. At time of lower conjunction the relative surface of the illuminated part of the disk constituted 0.007, and at the end of observations (28 May) — 0.34. Because of the low precision in antenna parameter determination, one may only assert that the difference in brightness temperatures for these two phases of Venus does not exceed 230° K.



March April May
Date of Observations

Fig. 6. Dependence of Venus' brightness temperature averaged for 10 — 15 days, on the date of observation.

The obtained value of brightness temperature at 4 mm., results close to its value at 8 mm [1, 2, 10], which is evidence of an apparent relatively small absorption of the emission in the planet's atmosphere. Further comparison with the results obtained during measurements in centimeter wavelengths allows to derive conclusions as regards the physical conditions on Venus.

**** THE END ****

Translated by ANDRE L. BRICHANT
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4 August 1962

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Institute of Physics in the name of P. N. Lebedev of the USSR Academy of Sciences, and Radiophysical Institute of the Gor'kiy State University in the name of N. I. Lobachevskiy,

Entered on 29 November 1961.

APPENDIX.

Notes *) and **) from page 6 :

*) Inasmuch as the solid angle of the main lobe of the pattern is substantially smaller than the solid angle of the Moon's disk, the quantity $T_Л$ practically corresponds to the temperature of the central part of the disk.

**) The estimate of components in (4) and (5) shows that a 7% error may then be acceptable on account of variations from measurement to measurement not accounted for. Besides, the quantity $T_Л$ is itself known with a precision to ±10%. Thus, the aggregate mean-square error that may appear at that stage of the processing, constitutes ±12%.